MODELING ENERGY CONSUMPTION IN THE DEFENSE LOGISTICS AGENCY

DEFENSE
LOGISTICS
AGENCY

Operations Research and Economic Analysis Office

May 1988

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Operations Research and Economic Analysis Office 6b. OFFICE SYMBOL (If applicable) DLA-LO	7a. NAME OF MONITORING ORGANIZATION Defense Logistics Agency (DLA-L)
6c. ADDRESS (City, State, and ZIP Code) Cameron Station Alexandria, VA 22304-6100	7b. ADDRESS (City, State, and ZIP Code) Cameron Station Alexandria, VA 22304-6100
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable) DLA-L	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code) Cameron Station Alexandria, VA 22304-6100	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

(U) Modeling Energy Consumption in the Defense Logistics Agency

12. PERSONAL AUTHOR(S)
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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Nov 86 TO Dec 87	May 1988	29

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Energy consumption

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The Defense Logistics Agency (DLA) Office of Installation Services and Environmental Protection was tasked with developing goals for energy consumption at each of the DLA-managed facilities. These goals could be based on factors which are beyond the control of the organization and can vary from month to month, such as weather conditions and workload. This report presents the results of an analysis that mathematically modeled energy consumption and then attempted to use these models to assist in setting consumption goals for the agency.

(continued)

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL Col Eugene Round, USAF	22b. TELEPHONE (Include Area Code) (202) 274-6715 22c. OFFICE SYMBOL DLA-LO

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. (continued)

The DLA facilities identified the factors which they considered to be predictors of energy consumption. Three years of monthly data were submitted for each factor. The data were screened to identify possible problems and to determine which factors had some relationship with energy consumption. Regression models were developed to predict total consumption, electric consumption, and non-electric consumption at each location. These models showed a definite relationship between weather and workload factors and energy consumption. However, the models were not accurate enough to be used to set consumption goals in DLA due to the impact of extraneous factors that were not quantifiable.

Goals for energy consumption should be flexible to allow changes when unusual weather or workload conditions exist. However, these goals cannot be derived through a precise mathematical formula given the existing detail of available data.

Modeling Energy Consumption

in the Defense Logistics Agency

November 1987

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DLA-LO

13 May 88

FOREWORD

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The DLA facilities identified the factors which they considered to be predictors of energy consumption. Three years of monthly data were submitted for each factor. The data were screened to identify possible problems and to determine which factors had some relationship with energy consumption. Regression models were developed to predict total consumption, electric consumption, and non-electric consumption at each location. These models showed a definite relationship between weather and workload factors and energy consumption. However, the models were not accurate enough to be used to set consumption goals in DLA due to the impact of extraneous factors that were not quantifiable.

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I. INTRODUCTION

A. Background. In the past, OSD established energy consumption goals based primarily on the previous years usage, ignoring mission changes and other relevant factors. Since the military services and agencies objected to this approach, OSD asked each service and agency to establish its own goals within certain guidelines. These goals should be set so that changes in workload and weather conditions can be accounted for and an accurate evaluation of conservation efforts can be made. The Office of Installation Services and Environmental Protection, DLA Environmental Policy Office, DLA-WS/DEPO, tasked each DLA controlled facility with developing a 10-year energy resources management plan to meet the proposed energy consumption goals set by DLA Headquarters. In order to set these goals, a model was needed to estimate the reasonable usage for each facility. The actual consumption could then be compared to this goal to determine the degree of success of the activity's management plan.

B. Purpose. The purpose of this analysis was to develop a methodology to calculate goals that are based on factors which can vary from month to month (i.e., weather and workload).

C. Objectives

1. Determine what factors (i.e., weather, workload), if any, have an influence on the amount of energy used at DLA managed facilities.

2. Use these factors to develop a model for each facility that will estimate the expected energy consumption given a set of values for the factors.

3. Evaluate the accuracy of the models and determine if it is feasible to use these models to monitor energy conservation efforts.

D. Scope. This analysis was limited to those DLA locations for which DLA manages energy consumption at the facility. Three years of monthly historical data were used to develop the models for each location. The models predicted consumption on the entire facility since meters were not available for individual buildings or processes.

II. CONCLUSIONS

Regression analysis did not produce models which could be used to set consumption goals for DLA with the existing detail of available data. Models were developed that predicted total energy usage, electric usage, and non-electric usage. Factors were included in the model if they were significant contributors to calculating expected energy consumption. These models were evaluated to determine if they were accurate enough to set goals for the DLA activities. Examination of the models' errors, as well as the confidence intervals placed on the predicted values, indicated that the models would not supply the precision needed to achieve the desired goal. Discussions with Installation Services personnel uncovered several possible reasons why the models may be impractical to use. Equipment changes that take place over time, command emphasis placed on conservation, and active conservation efforts would all have an effect on the data and cause any model developed to misstate predicted energy consumption.

Heating and cooling degree days were highly correlated with non-electric and electric energy consumption respectively; however, further examination of this data revealed a potential problem. The energy consumption data usually were not for a calendar month period. Rather, the data reflected the energy used during a utility's billing period. Therefore, new variables were created which averaged the heating and cooling degree days for the current month and the prior month.

III. RECOMMENDATIONS. Weather and workload factors definitely influence energy consumption at DLA facilities. However, a model to predict usage for a given set of weather and workload conditions cannot be developed accurately enough to be used to set consumption goals. Therefore, it is recommended that DLA-WS/DEPO determine some other technique to set these goals. This method should be flexible to allow the activity some leeway if the workload at a location changes significantly or if the weather conditions are abnormal. This would include raising the goal if conditions were worse than normal, as well as, lowering the goal if conditions were better.

IV. METHODOLOGY. Currently there is no method to monitor energy usage in individual buildings or for single pieces of machinery in DLA since meters are available only at the base level. For this reason, this analysis deals with the energy consumption for an entire facility. DLA-WS/DEPO requested that the methodology used to develop models for DLA locations be similar to the technique used by the Navy, which has an energy monitoring system used at the facility level. The Navy system uses a regression model to determine the expected energy consumption for the current year. This model is based on previous years' usages given various weather conditions and workload levels.

A. Database. Each DLA facility that is accountable for its energy usage was asked to supply a list of factors that could possibly influence its energy consumption. These lists were reviewed to determine if any location overlooked a possible factor or included a factor that was not a cause of energy usage but rather an effect of some other factor. When a decision was made on the factors to use in this analysis, the facilities were asked to supply at least three years of data for each of these factors. In addition, energy usage data for the same time period were also requested. The energy data were separated into two areas: electrical usage and non-electric usage.

B. Factor Evaluation

The first step in developing the energy consumption models was to examine the relationship between the factors submitted by the locations and the energy consumption at the location. This was accomplished by both plotting the data and using correlation analysis. Each of the proposed factors was plotted in two ways.

The first plot was a scattergram of the monthly factor values with the corresponding energy consumption values. This graphic presentation allowed a visual inspection of the data to determine if any transformation of the variables was necessary. Linear relationships between the factors were also easily recognized with these plots.

The factor values were plotted against time in the second set of plots. This was performed to examine the behavior of the variables during the three year period. Increasing, decreasing, or cyclical trends could be discovered, and the reasons for these occurrences could be investigated.

After the plots were examined and any necessary transformations were performed, a correlation analysis program was run to determine the degree of association between the factors and energy consumption. Examination of the correlations revealed the factors which would be the best predictors of energy consumption.

C. Model Development

After the data were examined and any necessary changes made, three regression analyses were performed for each DLA location. Regression models were developed to estimate total energy consumption, electric energy consumption and non-electric energy consumption. By examining these three models, we could decide whether it would be better to estimate total energy consumption or estimate consumption by type of energy (i.e., electric or non-electric).

The data were input into the regression program and a stepwise method of selecting variables for the model was used. Factors were allowed to enter the model if they were significant at the 90% level and if the R^2 value was judged to have a significant increase. At the end of the regression, each factor was checked to ensure that its importance warranted its inclusion in the model.

D. Model Evaluation. Residual values were calculated after a model was developed. These values were plotted to determine the accuracy of the model and its usefulness to evaluate energy consumption at the facility. By examining the plots, it was possible to detect any trends that existed in the residuals and whether adding another variable might improve the overall model. The magnitude of the error that still remained in the model was also calculated and confidence bounds placed on the predicted energy consumption value. These confidence bounds would show the range of values which expected energy consumption could be with a specified confidence.

V. ANALYSIS

A. Factor Screening

The list of factors that were used in this analysis for each location is contained in Appendix A. Scattergram plots of these factors with energy consumption were developed for all the data. The most obvious relationship existed between heating degree days and non-electric consumption and cooling degree days and electric consumption. Several workload factors showed indications of a causal relationship with energy consumption but none as strong as heating and cooling degree days.

The second set of plots, factor values over time, were a little more revealing. The expected wave-like plots for heating and cooling degree days occurred and appeared very similar to the plots of non-electric and electric energy consumption respectively. However, closer examination of the plots revealed that there appeared to be a one month lag between an increase or decrease in heating or cooling degree days and the corresponding change in energy consumption at some locations. Discussions with personnel at the field activities pinpointed the reason for this situation. The figures supplied by the facilities for energy consumption were based on utility bills which were received during the month. The majority of the bills were not for a calendar month period; rather they were for a month long period that began on a day other than the first of the month. This tended to complicate the analysis since energy consumption was not being compared to the heating or cooling degree days that occurred during the actual time period of the energy reading. Since most of the non-calendar month periods began near the middle of the month, it was decided to create two new variables for each location. These new variables were the average heating and cooling degree days for a month and the prior month. The two variables were the only additional ones created by transformations in this analysis.

A correlation analysis was then performed on the factors and energy data for each of the locations. The two month average heating and cooling degree days proved to be a good transformation since these transformed variables had the highest correlations with energy consumption at a majority of the facilities. With the exception of heating and cooling degree days, no other factor had a strong correlation with energy usage.

B. Model Construction and Review

Stepwise regression analysis was used to construct three models for each facility using the factors supplied from the sites and the transformed variables. The variables were allowed to enter and leave the model freely with a confidence level of 90%. At two locations no variables were significant enough to create a model for electric consumption. The remaining models were developed with R^2 ranging from .37 to .99. The models for each location are contained in Appendix B.

After the models were built, they had to be examined to determine their usefulness in setting energy usage goals. Plots of the residuals, the difference between the actual and predicted energy consumption for a month, revealed that the models were not as accurate as had been hoped. This was supported by the fact that the standard errors (S.E.) were extremely large. Calculating confidence intervals for the predicted value of energy usage resulted in bounds for the values that were so large as to be useless for setting goals. Attempts were made to introduce additional factors into the model to reduce prediction error, but this resulted in models which were worse than those originally developed. The models show that a definite relationship exists between weather and workload factors and energy consumption. However, the models were not accurate enough to be used for setting goals.

C. Possible Explanation. What would cause the models that were developed to be so inaccurate? Discussions with Headquarters and field personnel revealed a possible reason. Factors that could not be quantified yet have an impact on energy consumption exist in DLA. Several of these factors are described below.

1. Equipment Changes. Any increase or decrease in the amount of equipment at a location over time would effect the amount of energy used. In addition, replacing a piece of machinery with something newer would probably decrease usage since the more modern piece would usually use energy more efficiently. The most obvious situation in which this occurred in DLA was the increase in the amount of computer hardware located at the sites. Both microcomputers and DMINS terminals were being installed throughout DLA during this period. At the same time, some of the older equipment was being replaced by newer machines.

2. Command Emphasis on Conservation. If a commander of a facility emphasizes energy conservation, then the location might be expected to use less energy then if the commander was not as concerned about it. Commanders at the DLA activities changed during the data period used and their emphasis and direction could have affected usage.

3. Active Conservation Efforts. If the activities had already implemented a conservation program, or simply a single effort, then the energy usage should be decreasing but there would be nothing obvious in the data used to explain this trend.

Appendix A

<u>Factors Considered for Inclusion</u>

<u>in the Energy Model</u>

FACTORS CONSIDERED FOR INCLUSION

IN THE ENERGY MODEL

DDTC

Heating Degree Days

Cooling Degree Days

DDTC Employees

Tons Received

Tons Shipped

Lines Received

Lines Shipped

Trucks

Number of GBLs

Storage Tons

FACTORS CONSIDERED FOR INCLUSION

IN THE ENERGY MODEL

DDOU

Heating Degree Days

Cooling Degree Days

Overtime Hours

Reimbursable Work

Tons Received

Tons Shipped

FACTORS CONSIDERED FOR INCLUSION

IN THE ENERGY MODEL

DDMT

Heating Degree Days

Cooling Degree Days

Tons Received

Tons Shipped

Lines Received

Lines Shipped

FACTORS CONSIDERED FOR INCLUSION

IN THE ENERGY MODEL

<u>DPSC</u>

Heating Degree Days

Cooling Degree Days

Items Shipped

Total Direct Labor

Sponged Cloth

Regular Non-Manufacturing Labor

Overtime Non-Manufacturing Labor

FACTORS CONSIDERED FOR INCLUSION

IN THE ENERGY MODEL

DCSC

Heating Degree Days

Cooling Degree Days

Overtime Hours

Tons Received

Tons Shipped

Lines Received

Lines Shipped

FACTORS CONSIDERED FOR INCLUSION

IN THE ENERGY MODEL

DESC

Heating Degree Days

Cooling Degree Days

DESC Employees

Overtime Hours

FACTORS CONSIDERED FOR INCLUSION

IN THE ENERGY MODEL

DGSC

Heating Degree Days

Cooling Degree Days

Tons Received

Tons Shipped

Lines Received

Lines Shipped

DGSC Overtime Hours

DDRV Overtime Hours

DGSC Employees

DDRV Employees

Tenant Employees

Appendix B

Regression Results

The following abbreviations are used in this appendix to identify factors in the models.

HDD	Heating degree days during the current month
HDD1	Heating degree days during the prior month
CDD	Cooling degree days during the current month
CDD1	Cooling degree days during the prior month
LR	Lines received
STOR	Short tons on hand
LS	Lines shipped
TR	Tons received
GBL	GBLs (In and Out)
IS	Items shipped
POP	Total number of employees
Y	Energy consumption

REGRESSION RESULTS

DDTC

Total Energy Usage

$$Y = -679.37 + 10.98(HDD) + .115(LR) + 1.59(CDD) + 1.59(CDD1) + .0099(STOR)$$

$R^2 = .9324$

S.E. = 622.62

Electric Energy Usage

$$Y = 2289.64 + .0028(LS) + 1.07(CDD) + .057(TR) - .04(GBL) + .03(LR)$$

$R^2 = .7848$

S.E. = 174.49

Non-Electric Energy Usage

$$Y = -1484.31 + 9.47(HDD) + .013(STOR)$$

$R^2 = .9444$

S.E. = 563.69

REGRESSION RESULTS

DDOU

Total Energy Usage

$$Y = -120.45 + 5.27(HDD) + 1.03(HDD1) + .12(TR)$$

$R^2 = .9936$

S.E. = 243.20

Electric Energy Usage

No factors significant at the 90% level

Non-Electric Energy Usage

$$Y = 605.24 + 5.36(HDD) + .85(HDD1) + .087(TR)$$

$R^2 = .9945$

S.E. = 223.43

REGRESSION RESULTS

DDMT

Total Energy Usage

$$Y = 5461.98 + 12.24(HDD) + 12.24(HDD1)$$

$R^2 = .7062$

S.E. = 4564.37

Electric Energy Usage

$$Y = 4654.90 + .78(HDD) + .78(HDD1) + 1.90(CDD) + 1.90(CDD1)$$

$R^2 = .6418$

S.E. = 384.10

Non-Electric Energy Usage

$$Y = -408.58 + 12.44(HDD) + 12.44(HDD1)$$

$R^2 = .7332$

S.E. = 4340.98

REGRESSION RESULTS

DPSC

Total Energy Usage

$$Y = 7461.40 + 2.22(HDD) - .018(IS)$$

$$R^2 = .4862$$

$$S.E. = 989.08$$

Electric Energy Usuage

$$Y = 746.10 + 2.70(CDD) + 1.39(CDD1)$$

$$R^2 = .9241$$

$$S.E. = 198.59$$

Non-Electric Energy Usage

$$Y = 3530.75 + 8.17(HDD)$$

$$R^2 = .5632$$

$$S.E. = 842.36$$

REGRESSION RESULTS

DGSC

Total Energy Usage

$$Y = 5192.99 + 22.18(HDD) + 8.91(HDD1) + 6.39(CDD) + 6.39(CDD1)$$

$R^2 = .9214$

S.E. = 2438.99

Electric Energy Usage

$$Y = -2211.14 + 3.19(POP) + 2.05(CDD)$$

$R^2 = .3784$

S.E. = 796.25

Non-Electric Energy Usage

$$Y = -892.87 + 19.66(HDD) + 6.50(HDD1)$$

$R^2 = .9484$

S.E. = 1895.53

REGRESSION RESULTS

DESC

Total Energy Usage

$$Y = -362.68 + 28.22(HDD) + 5.78(HDD1) + 33.00(CDD)$$

$R^2 = .9683$

S.E. = 2310.28

Electric Energy Usage

$$Y = 6241.57 + 2.96(CDD) + 2.96(CDD1)$$

$R^2 = .6794$

S.E. = 362.22

Non-Electric Energy Usage

$$Y = -6932.94 + 28.12(HDD) + 28.93(CDD) + 6.31(HDD1)$$

$R^2 = .9685$

S.E. = 2379.24

REGRESSION RESULTS

DCSC

Total Energy Usage

$$Y = 5936.42 + 60.98(HDD) + 12.19(HDD1)$$

$R^2 = .9412$

S.E. = 7813.17

Electric Energy Usage

No factors significant at the 90% level

Non-Electric Energy Usage

$$Y = -4209.94 + 60.32(HDD) + 12.30(HDD1)$$

$R^2 = .9451$

S.E. = 7472.43